Introduction

Most areas of the Borana lowlands are characterized by a lack of rivers or other open surface water. Hoping to improve the living conditions of the Pastoralists, the Ethiopian government constructed many ponds in the Borana lowlands since the 1960s. These ponds attracted so many livestock near water points leading to overgrazing.

Heavy grazing can change the composition of plant communities (Landsberg *et al*., 2002). Lange (1969) discussed that interactions between animals and water points lead to the development of distinct ecological units, called piosphere. These piospheres are at immediate vicinities of livestock watering points and, therefore, are areas of high use. Grazing gradients (piosphere patterns) were defined as patterns that reflect the concentricity of stocking pressure around water points (Andrew and Lange, 1986). Overgrazing by domestic livestock has been considered as a major degrading factor because it changes vegetation structure and composition as a result of which some species increase in abundance and others decrease (Yates *et al*., 2000). Besides, it is the most pervasive cause of soil degradation (IFAD, 2003), which in turn, results in decline of herbaceous biomass production.

In contrary to the expected out put, development interventions such as pond construction contributed to rangeland degradation. Previous studies were qualitative and no/little quantitative data exists on the impact of herbivores on vegetation, soil and rangeland condition around water points in the Borana lowlands.

Therefore, the objectives of this study were to determine the impact of distance from water point on: 1) rangeland condition, 2) spatial distribution of herbaceous species and soil nutrients, 3) Woody plants cover and density.

Methods

Study site

The study was conducted in Dida Hara Pastoral Association (PA) in Yaballo district of the Borana lowlands, Ethiopia.

Sampling technique

Six line transects, each radiating in the north, south, east, west, northeast and southwest from the pond were used for sampling. Sampling plots were established along each transect at a distance of 0-50 m, 200-250 m, 400-450 m, 600-650 m, 800-850 m and 1000-1050 m, from the pond using a 50 m base line. 50, 200, 400, 600, 800 and 1000 are used as short hand of the above ranges, respectively.

Data collection

The study was conducted from June 2001 to August 2002. Environmental variables recorded at each sample plot were distance from pond, woody plants cover and density, proportions of bare ground and scores of rangeland condition.

Data on woody plants density was collected from a total of 36 plots of 50 m x 10 m (500 m^2) size. Samples of soil were collected from a total of 24 plots along four transects. Rangeland condition assessment data was collected from a total of 12 plots along two transects following the method adopted by Baars *et al*. (1997).

Surface soil samples (0-15 cm) were collected from these five subplots after scraping away any leaf litter and the five samples were pooled for a plot. Soil samples were analysed in the laboratory of the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia using standard methods.

Data Analysis

Correlation and linear regression analyses were performed using SPSS 11.5 for windows software. Density of woody species is defined as the number per area of the species. Multivariate techniques using the software CANOCO version 4.0 (ter Braak & Šmilauer 1998) were employed in order to explore the relationship among distance from the pond, grass species and environmental variables.

Results

Relationship between distance from the pond and rangeland condition scores

The rangeland condition assessment data was analysed using distance from Dambi pond as independent variable. There was a significant positive correlation between score of grass botanical composition and distance away from the pond (Table 1).

Table 1. t-values of regression coefficients of the relationship between distance from the pond and environmental variables (r = correlation coefficient).

Environmental factors	r	F	t-value	P
Grass botanical composition	0.266	4.412	2.101	0.04*
Basal cover	0.402	11.212	3.349	0.001***
Litter cover	0.225	3.104	1.762	0.083
Grass number of seedlings	0.386	10.163	3.188	0.002**
Grass age distribution	0.531	22.833	4.778	< 0.001***
Soil erosion	0.192	2.225	1.492	0.141
Total range condition score	0.383	9.959	3.156	0.003**

* = significant, ** and *** = highly significant.

A highly significant modest positive correlation was also found between distance from the pond and grass basal cover. Further regression analysis also revealed that there was significant linear relationship between distance from the pond and grass species basal cover. That is, grass basal cover increases as the distance from the pond increases.

There was highly significant positive correlation between score of number of grass seedlings and distance from the pond. This implies that number of grass seedlings increases as the distance from the pond increases.

The correlation between score of grass age distribution and distance from the pond was modest and highly significant (Table 1). In other words, young, medium and old age groups of the grass species were commonly available at distances away from the water point.

There was highly significant positive correlation between total score of rangeland and distance from the pond. Regression analysis also revealed that there was significant linear relationship between total score of rangeland condition and distance from the pond. Rangelands at close proximity of the pond were more deteriorated than those far away from the pond.

Relationship between distance from the pond and woody plants

The mean density of woody plants per each distance range is summarized in Table 2.

Table 2. Mean density (no. ± standard deviation) of woody plants as distance increases Dambi pond in the Borana lowlands, Ethiopia.

Distance (m)	Trees/shrubs	Saplings	Seedlings	Total
50	59.33 ± 48.88	9.67 ± 14.35	2.67 ± 3.33	71.67 ± 47.97
200	119.50 ± 61.31	16.67 ± 10.50	3.67 ± 3.50	139.83 ± 63.61
400	26.33 ± 21.00	30.33 ± 27.57	11.67 ± 13.54	68.33 ± 45.48
600	45.67 ± 43.89	24.33 ± 23.20	10.00 ± 9.17	80.00 ± 31.18
800	59.83 ± 38.52	17.50 ± 22.84	10.33 ± 10.97	87.67 ± 54.10
1000	34.67 ± 9.95	8.50 ± 6.80	4.67 ± 5.16	47.83 ± 10.82
0-400	68.39 ± 59.27	18.89 ± 19.86	6.00 ± 8.83	93.28 ± 60.20
600-1000	46.72 ± 33.83	16.78 ± 19.23	8.33± 8.66	71.83 ± 38.68

Density of woody plants was highest at the distance of 200 m from the pond. The zones at the immediate vicinity of the pond (0-50) and farthest away from the pond (1000-1050) were characterised by relatively low density of woody plants (Table 2).

In general, there were more woody plants in the distance range 0-400 than in the distance range 600-1000 from the pond. There was a weak negative correlation between density of trees/shrubs and distance from the pond.

Relationship between distance and soil nutrients

The mean values of soil nutrients and texture as well as the summary of regression analysis are presented in Table 3. There was a significant modest negative correlation between distance from the pond and total soil nitrogen. Regression analysis also revealed significant negative linear relationship. The result showed that soils close to the pond had more nitrogen than those far away from the pond.

Similarly, both correlation and regression analyses revealed that the relationship between distance from the pond and available soil phosphorus was negative and significant.

The relationship between distance from pond and calcium and cation exchange capacity of soil was also significant.

Table 3. Mean values of the soil nutrients and texture per distance from Dambi pond, Borana lowland, Ethiopia (Dist = distance from the pond, * = significant).

Dist (m)		N (%)	P (ppm)	OM (%)	pH (pH-H_20)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	CEC (meq/100g)	Sand (%)	Silt (%)	Clay (%)
50	Mean	0.21	27.7	4.13	6.56	4.33	19.70	3.22	32.52	45.14	29.64	25.22
	SD	0.09	22.7	1.89	0.19	1.24	8.46	0.86	11.03	14.95	7.80	10.25
200	Mean	0.13	9.5	2.46	6.34	2.99	23.80	4.04	37.80	47.78	18.32	33.90
	SD	0.05	8.09	0.95	0.48	0.76	15.30	1.86	16.68	20.32	12.30	11.94
400	Mean	0.13	15.00	2.38	6.69	2.42	21.90	3.02	33.00	52.39	18.89	28.72
	SD	0.07	24.50	1.28	0.41	1.39	19.30	1.38	22.47	13.27	5.10	17.49
600	Mean	0.15	4.99	2.99	6.16	3.46	19.20	4.09	36.04	41.80	23.33	34.87
	SD	0.06	5.93	1.31	0.17	1.68	13.50	1.02	12.66	21.15	10.60	10.85
800	Mean	0.11	1.22	2.12	6.27	2.44	8.48	3.16	19.50	56.78	17.07	26.15
	SD	0.04	0.72	0.90	0.11	1.19	2.96	1.12	3.90	8.99	3.60	7.04
1000	Mean	0.11	3.19	2.06	6.35	2.82	7.50	2.85	20.22	57.10	23.82	19.08
	SD	0.03	3.58	0.59	0.22	0.80	2.97	0.47	4.68	7.86	6.45	8.99

Regression analysis summary of the relationship between distance and soil nutrients and texture

	N	P	OM	pH	K	Ca	Mg	CEC	Sand	Silt	Clay
r	-0.42	-0.47	-0.39	-0.27	-0.32	-0.46	-0.16	-0.41	0.27	-0.15	-0.23
F	4.58	5.91	3.81	1.70	2.33	5.51	0.57	4.30	1.70	0.51	1.16
t-value	-2.14	-2.43	-1.95	-1.30	-1.53	-2.35	-0.76	-2.07	1.31	-0.71	-1.08
P	0.04*	0.02*	0.06	0.21	0.14	0.03*	0.46	0.05*	0.21	0.48	0.29

Impact of distance from the pond on distribution of herbaceous species

The herabaceous species showed clear patterns of distribution in relation to the distance from the pond. From the data in Figure 1, it was concluded that the unpalatable forb *Amaranthus thunbergii*, least palatable grasses such as *Echinochloa haploclada*, *Eleusine intermedia*, *Pennisetum setaceum*, and *Eragrostis cilianensis* were most abundant in the plot closest to the pond and nearly absent in the plot farthest away from the pond. On the other hand, *Cynodon dactylon* and the annual grass *Setaria verticillata* were also most abundant in the plot closest to the pond. *Cynodon dactylon* was common on highly disturbed or overgrazed areas like edge of the pond.

DCA revealed that highly palatable and desirable grasses such as *Cenchrus ciliaris* and *Digitaria milanjiana* were more abundant on sites farthest away from the pond (Figure 1). The least palatable species are more frequent near the pond, whereas frequency of highly palatable species increases as distance from the pond increases.

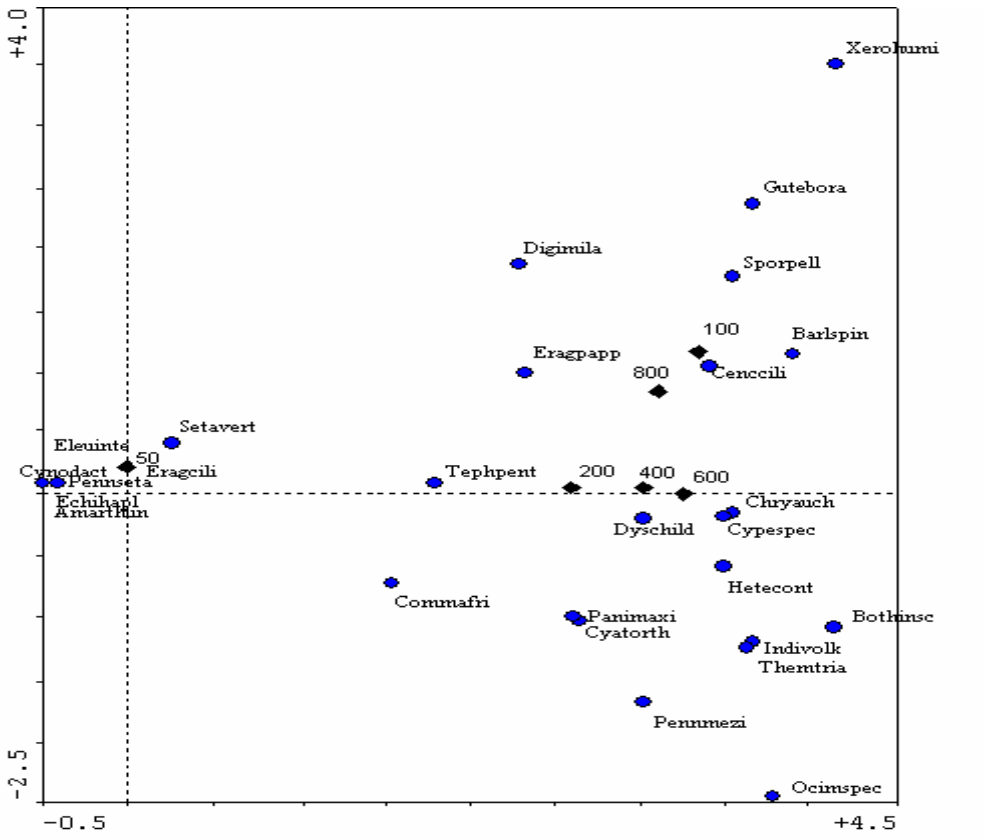

Figure 1. DCA ordination diagram of grass species surrounding Dambi pond. Circles represent species, whereas sites are represented by diamonds and their distance from the pond.

Relationship among distance from the pond, herbaceous species and environmental variables

RDA analysis revealed that soils in the radius of 50 m from the pond contained more silt, those in the radius of 200-600 m more clay, and 800-1000 m away from the pond had higher proportion of sand. Furthermore, three major herbaceous vegetation types were identified: *Eleusine intermedia-Cynodon dactylon* at the closest vicinity of the pond (0-50 m) and, thus, positively correlated with soils of higher proportions of silt. The second community was *Pennisetum mezianum-Themeda triandra* at 400-600 m, associated with higher proportion of clay and the third *Chrysopogon aucheri-Sporobolus pellucidus* at 800-1000 m and positively correlated with more sand in soil texture (Figure 2). Highly

desirable and most intermediate forage grasses were closely associated with high proportion of sand in the soil texture.

Higher proportion of the bare soil was associated with the immediate vicinity of the pond (0-50 m) and density of trees/shrubs, total nitrogen, available phosphorus, organic matter, potassium and pH were closely associated with the distance range between 50-200 m. On the other hand, cover of woody plants and herbage mass were higher at the 400-600 m distance from the pond. Note that herbage mass was negatively correlated with bare ground and the 0-50 m distance zone from the pond.

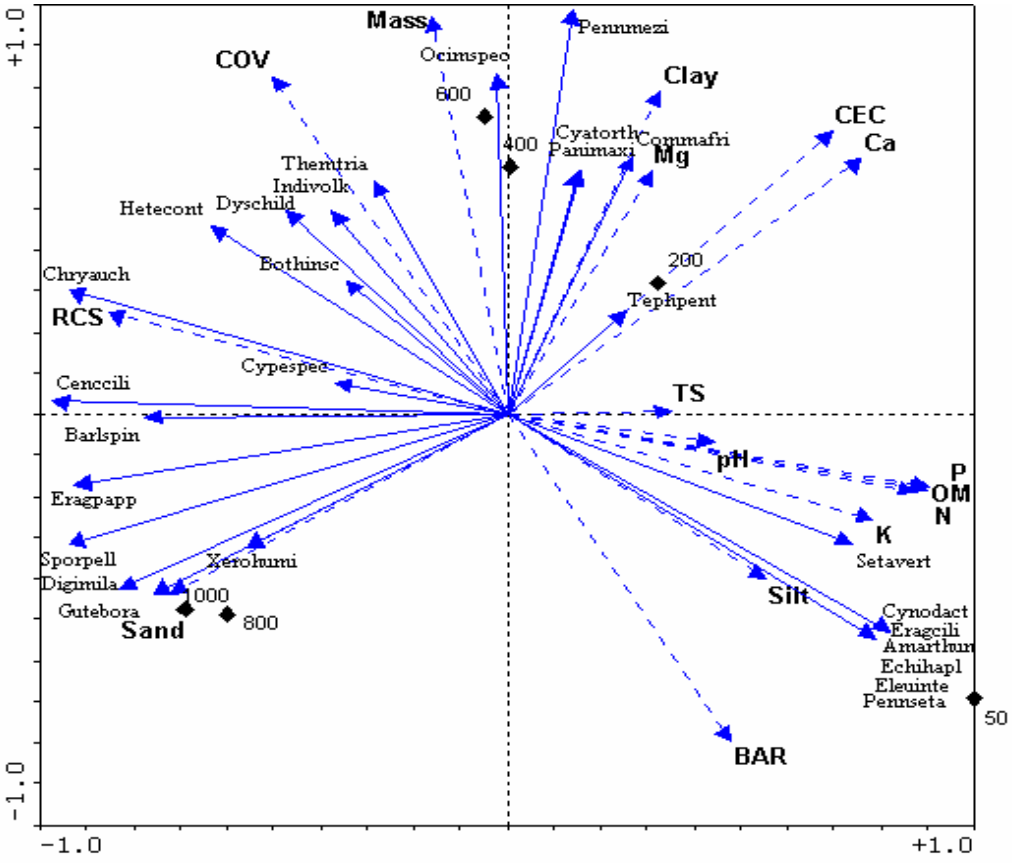

Figure 2. RDA ordination triplot of the relationship among distance from pond, environmental variables and grass species spatial distribution. Abbreviations: COV = Percent canopy cover of woody plants; TS = density of trees/shrubs; Mass = herbage mass; RCS = total score of rangeland condition; BAR = Percent bare ground.

Total score of rangeland condition showed positive relationship with the distance $\geq$ 400 m but more strongly correlated with those at 800-1000 m from the pond. That is,

rangelands at distances greater than 400 m away from the pond were in better status than those closer to the pond. In general, as distance away from the pond increases, rangeland condition becomes relatively better. The other interesting result of the analysis was that rangeland condition score was negatively correlated with density of trees/shrubs and bare ground. In other words, density of trees/shrubs and bare ground were positively correlated, both of them contributing to rangeland degradation.

Total nitrogen, available phosphorus and organic matter were highly correlated and cation exchange capacity, calcium, magnesium and clay are also positively correlated.

Discussion

Gradients of utilization pressure develop around water points, with the greatest impact near the water point and decreasing pressure as distance away from the water point increases (Brits *et al*., 2002). This study showed that differences in grazing gradient surrounding Dambi pond is reflected in differences of vegetation composition and spatial distribution of soil nutrients, and also appears to contribute to decline in rangeland condition. Yates *et al*. (2000) discussed that higher grazing pressure of livestock was associated with a decline in perennial and increase of annual cover, reduced litter cover and increased soil erosion, changes in the concentrations of soil nutrients, degradation of surface soil structure, reduced soil water infiltration rates and changes in near ground and soil microclimate.

Impacts of water points on rangeland condition

RDA multivariate analysis identified three zones within the range of 0-1000 m distance: 0-50, 200-600 and 800-1000 m away from the pond. Unpalatable forbs and least palatable grasses characterise the zone at immediate vicinity of the pond (0-50 m), whereas the zone farthest away from the pond was characterized by high abundance of highly desirable and palatable grasses. Highly palatable grass species such as *Cenchrus ciliaris* and *Digitaria milanjiana* were most abundant in the 800-1000 m zone. Therefore, it was concluded that the proportions of desirable species increase as the distance away from the pond increases.

This study concurs with previous studies. For example, Hunt (2001) reviewed that within areas cantered on water points in which grazing pressure attenuates with distance from

water (the piospheres), as distance from the water point decreases, palatable perennial plants decline in density or eliminated and are replaced by unpalatable and/or short-lived species. Similarly, Landsberg *et al*. (2002) reported that palatable, drought-hardy, perennial species are more likely to decline in abundance with proximity to water point. Density of woody plants was much lower (1433/ha) in the zone directly adjacent to the pond but highest (2780 /ha) at 200 m away from the pond. This result concurs with that of Brits *et al*. (2002).

This study revealed that as the distance away from the pond increases, the number of grass seedlings also increases. Yates *et al*. (2000) reported that in overgrazed areas soil water could be below the critical threshold for seed germination and seedling establishment. Therefore, the result of this study may show that highly overgrazed rangelands closer to the pond had resulted in reduced soil water infiltration and storage. Compared with areas farther away from the pond, rangeland condition was worse in areas closer to the pond. Water points contribute to deterioration of rangeland condition and change in vegetation composition.

Soil nutrients

Soil analysis revealed that total nitrogen, available phosphorus, calcium and cation exchange capacity of the soil nutrients varied significantly with distance from the pond. There was higher concentration of total nitrogen and available phosphorus close to the pond. This may be due to defecation and urination of the livestock. Yates *et al*. (2000) reported that concentrations of soil nitrogen and available phosphorus were significantly higher in heavily grazed woodlands. Yates *et al.* (2000) reported that the high concentration of soil nitrogen and phosphorus might be attributable to livestock bringing nutrients into the system from surrounding landscapes in the form of urine and faeces. Furthermore, the spatial distribution of these nutrients reported in this study also concurs with other studies (Turner, 1998) in that soils near the pond had higher proportions of N and P.

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